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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI. EXPERIMENT

Simulation of the Momentum Distributions of the Spectator Fragments in ^{124}XeB Collisions at the BM@N with Accounting for Pre-Equilibrium Clusterization

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Abstract—In this work the Abrasion-Ablation Monte Carlo for Colliders model with and without MST-clustering was employed to characterise the momentum distribution of produced spectator fragments. The simulation results suggest that pre-equilibrium fragmentation with accounting for Coulomb interaction between charged spectator fragments lead to an increase of their mean transverse momentum p_T, bringing the calculations closer to experimental data. The pseudorapidity distributions of H, He, Li spectator fragments from 3.26A GeV ^{124}XeB collisions at the BM@N were calculated.

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1. INTRODUCTION

The understanding of the momentum distributions of spectator fragments in relativistic nucleus-nucleus collisions is necessary for the estimation of the performance of forward detectors, in particular FHCal and SciWall at the BM@N [1]. To correctly simulate their response, a model providing realistic momentum distributions of charged spectator fragments is needed, so it is required to account for the Coulomb repulsion in the fragmentation [2, 3]. Furthermore, in the 50A MeV Xe + Sn reaction, a discrepancy between QMD calculations and experimental data, in particular, lower kinetic energies and stronger in-plane flow of fragments, was attributed to the neglect of Coulomb repulsion [3].

In this work the Abrasion-Ablation Monte Carlo for Colliders model with (AAMCC-MST) and without (AAMCC) pre-equilibrium clusterization was employed to simulate the production of spectator fragments [4]. Previous studies show that pre-equilibrium fragmentation improves the agreement between AAMCC results and experimental data on the yields of spectator protons, neutrons, and He fragments [4]. However, the momentum of the spectator fragments was not analysed in details previously. In this work Goldhaber model [5] is used to account for the intranuclear motion of removed nucleons. The Coulomb repulsion of the charged fragments were considered at the last stage of MST-clusterization. Obtained pseudorapidity and p_T distributions of spectator fragments were compared with data from the KLMM collaboration [6, 7]. Finally, the pseudorapidity distributions of spectator neutrons, protons, He and Li fragments in 3.26A GeV ^{124}XeB collisions at BM@N were calculated and the fraction of the undetected fragments were estimated.

2. OUR MODEL ABRASION-ABLATION MONTE CARLO FOR COLLIDERS

In the AAMCC the first stage of nucleus-nucleus collisions are modelled by means of Glauber Monte Carlo [8]. It is assumed that excited spectator fragments (prefragments) are formed by non-participating nucleons. The excitation energy of the prefragment is estimated as described in [4]. The MST-clustering algorithm is employed to model the pre-equilibrium fragmentation [4], while the Statistical model of multifragmentation (SMM), Weisskopf-Ewing evaporation model and Fermi break up model in realization of Geant4 [9] are used to model the decay of the excited fragments after the MST-clustering. In the MST-clustering, nucleons are represented by vertices in a complete graph, with edge weights as distances between them. Nucleons i and j are clustered if $r_{ij} < d$, forming prefragments. Following the method by Kopylov [10], the excitation energy of free spectator nucleons is converted into kinetic energy of the formed prefrag-

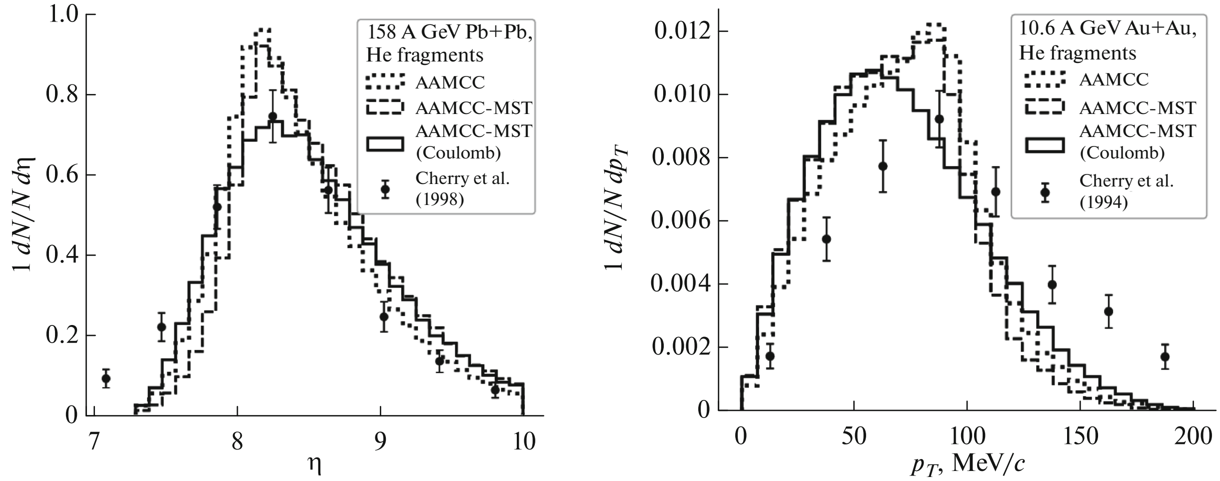

Fig. 1. The pseudorapidity distribution of spectator He fragments in the 158*A* GeV Pb + Pb collisions (left) and the transverse momentum p_T distribution of spectator He fragments in 10.6*A* GeV Au + Au collisions (right) for AAMCC (dotted line), AAMCC-MST (dashed line), AAMCC-MST with Coulomb repulsion (solid line) models.

ments and nucleons. The prefragment expansion is emulated in the MST-clustering by decreasing the clustering parameter d. The ratio between distance and nuclear density is assumed to be $d \propto \rho^{\frac{1}{3}}$. The density parametrization is a piecewise function based on experimental data, as described by the following equation:

$$d = \begin{cases} d_0, & \text{if } \varepsilon^* < \varepsilon_s, \\ d_0\left(\gamma \exp\left(-\left(\frac{\varepsilon^*}{\beta}\right)^{\alpha}\right) + \delta\right)^{\frac{1}{3}}, & \text{if } \varepsilon^* \geq \varepsilon_s. \end{cases}$$

Parameters are obtained by fit of the experimental data on excited nuclear density [11]: $d_0 = 2.7$ fm, $\alpha = 2.24$, $\beta = 3.18$ MeV, $\gamma = 0.99$, $\delta = 0.29$, $\varepsilon_s = 2.17$ MeV.

According to the Goldhaber statistical model [5] the removed nucleons total momentum distribution is assumed to be Gaussian with

$$\sigma^2 = \sigma_0^2 \frac{N_{\text{specA}} N_{\text{partA}}}{A - 1},$$

where A is the mass of the colliding nuclei, N_{specA} and N_{partA} are corresponding spectator and participant numbers. The $\sigma_0 = 193$ MeV is model parameter and was chosen to correspond to the Fermi momentum of the nucleons in heavy nucleus.

To efficiently simulate the Coulomb repulsion of the prefragments after the MST-clusterization the Barnes-Hut algorithm was employed. It approximates the force calculations by grouping nearby protons into a single charge [12]. For a distant region with center $\vec{a}$, size s and the center of charge $\vec{r}_c$, if the condition $\frac{s}{|\vec{a} - \vec{r}|} < \theta$ is met, internal protons are approximated as a single charge at $\vec{r}_c$. The simulation of the motion of the charged fragments lasts until the velocities of the fragments are established, that takes $\sim 1000\ \frac{\text{fm}}{c}$. The cutoff parameter θ is set to 0.3. The adaptive time step is set to value such that momentum change of any proton or prefragment is restricted by 5%, but less than $3\ \frac{\text{fm}}{c}$.

3. MOMENTUM AND PSEUDORAPIDITY DISTRIBUTIONS OF THE LIGHT SPECTATOR FRAGMENTS

As it can be seen in Fig. 1 (left) the pseudorapidity distribution of spectator He fragments from 158*A* GeV Pb+Pb collisions by AAMCC-MST is close to the one obtained from AAMCC, but both versions underestimate the width of the distribution. However, the inclusion of Coulomb interactions, as described in Section 2, between charged fragments leads to a better agreement with the experimental data. The transverse momentum p_T distribution of spectator He fragments in 10.6*A* GeV Au+Au collisions, Fig. 1 (right), is overestimated for $p_T \leq 100$ MeV/c and underestimated for $p_T \geq 100$ MeV/c by both AAMCC and AAMCC-MST models. But with accounting for the Coulomb repulsion the underestimation of fragments with $p_T \geq 100$ MeV/c is reduced, bringing the AAMCC-MST model calculations closer to the experimental data. The SciWall at the BM@N can detect spectator nucleons and fragments with $Z \leq 3$ in the 0–60% centrality collisions, while the hole inside it limits pseudorapidity of the detected fragments to $\eta > 5.48$ [1]. Pseudorapidity distributions for spectator fragments in 3.26*A* GeV XeB collisions at 0–60% centrality for H,

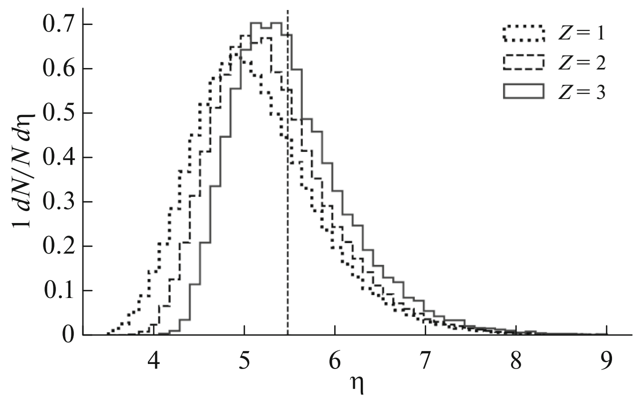

Fig. 2. The pseudorapidity distribution of spectator H (dotted line), He (dashed line), and Li (solid line) fragments from Xe + CsI 3.26A GeV collisions with centrality 0–60%.

He, and Li were calculated by means of AAMCC-MST with accounting for Coulomb repulsion, see Fig. 2. The estimated fractions of undetected spectator fragments are 27% for H, 34% for He, and 45% for Li. An increase of the average pseudorapidity with an increase of the fragment charge is obtained, suggesting the higher acceleration of the lighter fragments in the Coulomb interactions.

4. CONCLUSIONS

In this study, the momentum distributions of spectator fragments produced in relativistic collisions were simulated using the Abrasion-Ablation Monte Carlo for Colliders (AAMCC) model. Coulomb interactions between prefragments in the MST clustering were also considered. The results suggest that the pre-equilibrium fragmentation and Coulomb interactions between spectator fragments increase the mean p_T of light spectator fragments by approximately 20 MeV/c as a result of their repulsion from heavier fragments, that brings the simulation results closer to the experimental data. The pseudorapidity distributions of spectator H, He, and Li fragments were calculated for 3.26A GeV ^{124}Xe + CsI. The model predicts a significant fraction of undetected fragments by the SciWall detector at the BM@N, in particular, 27% for H, 34% for He, and 45% for Li.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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